

Restoration of walking in patients with incomplete spinal cord injuries by use of surface electrical stimulation — preliminary results

T. BAJD*, B. J. ANDREWS, A. KRALJ* and J. KATAKIS

Bioengineering Unit, University of Strathclyde, Glasgow

**Faculty of Electrical Engineering, Edvarda Kardelja University, Ljubljana*

Abstract

A group of patients who are good candidates for the application of Functional Electrical Stimulation (FES) to restore reciprocal walking is described. They have incomplete lesions of the spinal cord. Because of the degree of preserved voluntary control, proprioception and sensation some of these patients can achieve crutch assisted walking by means of multichannel electrical stimulation. In a number of cases the patient has sufficient strength and voluntary control in the upper limbs and at least one leg to provide safe standing for short periods in forearm crutches. For these patients a two channel stimulator controlled by a handswitch was applied to achieve safe and practical crutch assisted walking in a relatively short period of time.

Background

A new group of patients which can benefit from the orthotic use of functional electrical stimulation (FES) has been identified. These are incomplete spinal cord injured patients. This group of patients is increasing in numbers mainly due to improvements in primary care.

The clinically incomplete lesion of their spinal cord results in preservation of some voluntary movements of the lower extremities. Some of these patients are able to walk with the help of various short-leg or long-leg orthoses which fix the knee and ankle joints. Support of the foot is often provided by the addition of a toe spring. Locomotion of most other incomplete spinal cord injured (SCI) patients is performed with the help of a wheelchair. They can walk only for very short distances, usually in their homes.

Some tetraplegic patients are totally confined to a wheelchair. The reason is often very strong spasticity or developed contractures. The upper extremities are also partially paralysed. Nevertheless, the arms and hands are strong enough to provide support on crutches. Wrist and finger movements are often limited and the grip is rather weak. However, the patients are in most cases able to hold the handle of the crutch.

It was found that a minimum of four channels of FES was required for synthesis of a simple reciprocal gait pattern in the complete thoracic patient (Bajd et al, 1983; Kralj et al, 1983). During the stance phase, knee extensor muscles are stimulated, while the swing phase is accomplished by eliciting a synergistic flexor response in hip, knee and ankle joints through electrical stimulation of an afferent nerve. It was observed in the present study that in most of the incomplete tetraplegic patients one leg was almost completely paralysed while the other leg was under voluntary control and sufficiently strong to provide safe standing for short periods using only crutches. Unilateral stimulation of knee extensors and an afferent nerve was helpful in these patients. Less frequently it was found that the patients could stand but were unable to take a step with one or both legs. Unilateral or bilateral stimulation of afferent nerves proved helpful for them. There are also patients whose extension and flexion capabilities in both lower extremities are so poor that they need three or even four channels of stimulation.

The FES orthosis

From the point of view of control of the patient the gait cycle was divided into stance and swing phase. The transition from one phase to another was achieved by pressing a hand switch mounted on the handle of the crutch. When the switch was not pressed knee extensors were

All correspondence to be addressed to Dr. B. J. Andrews, Bioengineering Unit, Wolfson Centre, University of Strathclyde, 106 Rottenrow, Glasgow G4 0NW, Scotland



Fig. 1. Left, paraplegic subject with incomplete lesions at T6/7 walking on a level surface, end of the swing phase for the paralysed leg. Centre, tetraplegic subject with incomplete lesion at C6 walking on uneven ground: end of the swing phase for the paralysed leg. Right, same subject negotiating uneven steps.

stimulated. When the switch was pressed the afferent nerve was excited resulting in the swing phase of walking. The duration of the swing phase was regulated by the time of pressing the switch. In the present investigation the peroneal nerve was stimulated near fossa poplitea. The stimulation of this mixed, sensory and motor, nerve provided direct dorsiflexion and eversion of the foot and simultaneously also the reflex knee and hip flexion.

The gait of most of the incomplete SCI patients can be restored by the two-channel stimulator only. Any stimulator can be used for the described application, where the stimulation parameters can be adjusted close to the following values: 0.3 ms pulse duration, 20 Hz pulse repetition frequency, and an amplitude up to 120 volts (measured with a 1k Ω load). Surface electrical stimulation of the knee extensors was delivered to the muscles through large (6 $\times$ 4 cm) sheet metal electrodes covered with water soaked layers of gauze. When stimulating the common peroneal nerve two small round electrodes (diameter 2.5 cm) were used made of sheet metal and covered by gauze saturated with water. The interconnection of the hand switch

with the outputs of the stimulator to the electrodes can be readily accomplished. The hand switch was attached to the handle of the crutch by adhesive tape for trial purposes.

Patient tests

Five patients with incomplete spinal cord lesions have so far been included in the programme of FES assisted walking. Only a short strengthening programme was required for disuse atrophy of their thigh muscles. The learning programme of walking was extremely fast and simple. After the first few days the patients were able to go from mobile parallel bars to crutches (Fig. 1, left). The difference between walking with and without FES was evident. The patients were not able to take a single step with their severely paralysed extremity when the stimulator was switched off. After a few days of training they were able to rise from the sitting to the standing position independently with the help of the crutch support and knee extensor stimulation only. Soon they were able to walk on uneven ground (Fig. 1, centre) and go up and down steps (Fig. 1, right). The subject shown in Figure 1, left has an

incomplete lesion at the level T6/7 (age 36 yrs, height 168 cm, mass 61 kg, 7 yrs post injury). The subject shown in Figure 1, centre and right has an incomplete lesion at the level C6 (age 21 yrs, height 188 cm, mass 70 kg, 3 yrs post injury). In both cases one leg was paralysed whilst the other had sufficient voluntary control to maintain safe standing with crutches without stimulation.

Discussion

Such activities can only be achieved in a few completely paraplegic patients after many months in the training programme. These differences between incomplete and complete spinal cord injured patients are due not only to the remaining voluntary movements of their lower extremities but also to the preserved sensation and proprioception. The present FES orthotic systems provide active movements at the joints of the limbs but no feedback is available in practical clinical systems. The patients feel safe and secure when unattended because in the event of a failure of the orthosis they are able to support themselves. For these reasons the incomplete SCI patients appear to be the most appropriate candidates for FES. The FES assisted walking may require less energy from the SCI patients with incomplete lesions than walking with passive mechanical knee and ankle orthoses because no hip hiking is necessary with active FES systems. Finally, FES

assisted walking is much more aesthetic to the observer than orthoses assisted and is preferred by the patients. There may be a number of therapeutic benefits to be gained from the use of FES orthoses such as the prevention of pressure sores, contractures, muscle atrophy and bone demineralisation.

Acknowledgements

The authors wish to acknowledge the financial support of the Multiple Sclerosis Society and the A. Onassis, Public Benefit Foundation. The work was conducted at the Bioengineering Unit, University of Strathclyde, Head, Prof. J. P. Paul and in collaboration with Mr. P. A. Freeman F.R.C.S. and staff of the West of Scotland Spinal Injuries Unit at the Philipshill Hospital, Glasgow.

REFERENCES

- BAJD, T., KRALJ, A., TURK, R., BENKO, H., SEGA, J. (1983). The use of a four channel electrical stimulator as an ambulatory aid for paraplegic patients. *Phys. Ther.*, **63**, 1116-1120.
- KRALJ, A., BAJD, T., TURK, R., KRAJNIK, J., BENKO, H. (1983). Gait restoration in paraplegic patients. A feasibility demonstration using multichannel surface electrodes FES. *J. Rehabil. Res. Dev.*, **20**, 3-20.